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Title: Mixed-method pre-cooling reduces physiological demand without improving performance of medium-fast bowling in the heat.

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Abstract

This study examined physiological and performance effects of pre-cooling on medium-fast bowling in the heat. Ten, medium-fast bowlers completed two randomized trials involving either cooling (mixed-methods) or control (no cooling) interventions before a 6-over bowling spell in 31.9±2.1°C and 63.5±9.3% relative humidity. Measures included bowling performance (ball speed, accuracy and run-up speeds), physical characteristics (global positioning system monitoring and counter-movement jump height), physiological (heart rate, core temperature, skin temperature and sweat loss), biochemical (serum concentrations of damage, stress and inflammation) and perceptual variables (perceived exertion and thermal sensation). Mean ball speed (114.5±7.1 vs. 114.1±7.2 $km^{.}h^{-1}$; *P*=0.63; d=0.09), accuracy (43.1±10.6 vs. 44.2±12.5 AU; *P*=0.76; d=0.14) or total run-up speed (19.1±4.1 vs. 19.3±3.8 $km^{.}h^{-1}$; *P*=0.66; d=0.06) did not differ between pre-cooling and control respectively; however 20-m sprint speed between overs was 5.9±7.3% greater at Over 4 after pre-cooling (*P*=0.03; d=0.75). Pre-cooling reduced skin temperature after the intervention period (*P*=0.006; d=2.28), core temperature and pre-over heart rates throughout (*P*=0.01-0.04; d=0.96-1.74) and sweat loss by 0.4±0.3 kg (*P*=0.01; d=0.34). Mean rating of perceived exertion and thermal sensation were lower during pre-cooling trials (*P*=0.004-0.03; d=0.77-3.13). Despite no observed improvement in bowling performance, pre-cooling maintained between-over sprint speeds and blunted physiological and perceptual demands to ease the thermoregulatory demands of medium-fast bowling in hot conditions.

Introduction

Medium-fast bowling in cricket is a dynamic and physically taxing activity that requires combined tactical and technical proficiency for competitive success (Woolmer, Noakes & Moffett, 2008). Specifically, medium-fast bowling in first-class cricket involves repetitive high-intensity bouts (n= 50 – 56 efforts$\cdot$h^{-1}) separated by extended periods of predominantly lower-intensity fielding activities, with players covering ~22 – 24 km in a full day's play (Petersen, Pyne, Dawson, Portus & Kellett, 2010a; Petersen, Pyne, Portus & Dawson, 2011). Compounding these physical demands, seasonal scheduling of competition in hot and humid environments magnifies physiological and perceptual demands as effective heat transfer is reduced (Wendt, van Loon & van Marken Lichtenbelt, 2007). Subsequently, exercise in hot conditions can increase thermoregulatory, cardiovascular and metabolic demands (Morris, Nevill & Williams, 2000), while decreasing fluid volume (González-Alonso, 1998), neuromuscular function (Kay et al., 2001) and exercise performance (Drust, Rassmussen, Mohr, Nielsen & Nybo, 2005). These larger physiological and perceptual demands, along with anticipation of ensuing challenges to thermoregulation, reduce exercise intensity in the heat (Tucker, 2009). Accordingly, hot/humid conditions can increase thermal strain (Gore, Bourdon, Woolford & Pederson, 1993) to the detriment both of medium-fast bowling performance (Devlin, Fraser, Barras & Hawley, 2001) and health status (Driscoll, Cripps & Brotherhood, 2008; Finch & Boufous, 2008).

Pre-cooling strategies have been promoted to improve intermittent-sprint exercise in the heat (Castle et al., 2006; Duffield & Marino, 2007; Minett, Duffield, Marino & Portus, 2011). Increased heat storage reserves achieved with pre-cooling offset metabolic and environmental heat gain, protecting neuromuscular function to prolong higher self-selected exercise intensities (Duffield, Green, Castle & Maxwell, 2010; Skein, Duffield, Cannon & Marino, 2011). While the ecological validity of cold-water immersion in the field is accompanied by difficulties of implementation (Marino, 2002), the combination of multiple part-body cooling apparatus offers viable alternatives for pre-cooling in the field (Quod et al., 2008; Duffield, Steinbacher & Fairchild, 2009c; Ross et al., 2011). Provided sufficient dosage (surface area coverage, duration and temperature) of cooling stimulus is applied (Duffield, 2008; Bogerd, Perret, Bogerd, Rossi & Dannen, 2010; Minett, Duffield, Marino & Portus, 2011), a practical, mixed-method approach to pre-cooling could provide ergogenic assistance to medium-fast bowling performance, and/or reduce the physiological and perceptual loads encountered with prolonged bowling spells in the heat.

Given the importance of medium-fast bowling to team success (Wormgoor, Harden & McKinon, 2010) and the regularity of elite-standard competition in hot conditions (Petersen et al., 2010b), pre-cooling is a possible protective strategy for the maintenance or improvement of medium-fast bowling performance in the heat. However, while pre-cooling might aid intermittent-sprint exercise, (Castle et al., 2006; Duffield & Marino, 2007; Duffield et al., 2009c; Minett et al., 2011), limited data are available to evaluate its effects on sports-specific skill performance (Hornery, Farrow, Mujika & Young, 2007). Further, mixed-method pre-cooling techniques developed under laboratory conditions are untested in task-representative settings (Duffield et al., 2009c). Hence, the aim of this investigation was to determine physiological, perceptual and performance effects of mixed-method pre-cooling on a 6-over spell of medium-fast bowling in the heat. Pre-cooling was hypothesized to improve performance and reduce the physiological demand of medium-fast bowling in the heat.

Methods

Participants

Ten, well-trained, male, medium-fast bowlers were recruited for this study (mean ± standard deviation: age 23 ± 8 y; stature 189.8 ± 8.8 cm; body mass 84.9 ± 12.6 kg). Participants were senior-level club cricketers or junior state-based players and reported ≥ 5 training and competition days on a weekly basis. After explanation of experimental risks and procedures, all participants provided written and verbal informed consent and ethics approval was granted by the Ethics in Human Research Committee of the University.

Overview

A randomised, repeated-measures cross-over design was used to examine the effects of a field-based pre-cooling intervention on performance, physiological and perceptual responses during a 6-over medium-fast bowling spell in hot conditions. Participants were accustomed to all equipment and procedures before completing two standardised testing sessions separated by 3-5 days. All testing was completed during the in-season phase of competition. Sessions were identical, with only the pre-cooling intervention altered throughout. Participants completed two respective trials, including a control session (no pre-cooling) and a 20-min pre-cooling session (mixed-method pre-cooling). Each testing session involved a 6-over bowling spell based on an adaptation of the Cricket Australia-Australian Institute of Sport fast bowling skills test (Portus, Timms, Spratford, Morrison & Crowther, 2010). All data collection was conducted outdoors in mean ± standard deviation environmental conditions of 31.9 ± 2.1°C and 63.5 ± 9.3% relative humidity. Participants abstained from strenuous exercise and alcohol 24 h before and all caffeine and food substances 3 h before each testing session. Physical activity records and food diaries were documented for 24 h leading into the initial session and repeated for the remaining trial.

Exercise protocol

All testing was completed at a cricket-specific outdoor training facility on a centre-square turf wicket. The exercise protocol involved a modified version of that previously described by Duffield, Carney and Karppinen (2009a). Before commencement, participants completed a standardized 10-min warm-up consisting of jogging, sprinting and 10 practice deliveries, gradually increasing bowling speed to match intensity. Participants then performed a 6-over bowling spell at match intensity based on the Cricket Australia-Australian Institute of Sport fast bowling skills test, whereby players aimed to bowl deliveries of pre-determined line (right- and left-handed batsmen) and length (short, good length, and full deliveries) to replicate skill-based match requirements. Bowling in pairs and alternating overs, participants aimed to hit specific targets as instructed before each delivery that were highlighted on a 20 x 20-cm vertical grid positioned on the popping crease at the batsmen's end. The order of delivery type was standardized for each bowler as per the 4-over Cricket Australia-Australian Institute of Sport test, with the initial two overs replicated to extend the bowling spell in overs five and six. Each bowling spell was completed using a new regulation four-piece (156 g) cricket ball (Turf White, Kookaburra, Melbourne, Australia). Participants completed physical activities between overs to simulate match demands, including walking 10 m to correspond with each delivery and sprinting 20 m on the 2nd and 4th balls of each over. All fluid intake was restricted during the bowling spell.

Pre-cooling intervention

Pre-cooling involved a modified mixed-method approach as previously detailed (Minett et al., 2011). In brief, participants were cooled for 20 min in a seated position using a cold, wet towel placed over the head, neck and shoulders, ice-vest covering the torso (Arctic Heat, Brisbane, Australia), their non-bowling hand was immersed to the wrist in cold water (9.0 ± 0.5°C) and ice-packs were applied to the quadriceps muscle of each leg (Techni Ice, Frankston, Australia). Ice-vests and ice-packs were stored at -20°C, while cold, wet towels were soaked in cold water (5.0 ± 0.5°C) before application. Participants sat passively for 20 min and received no cooling during control trials.

Performance measures

Bowling performance was determined throughout the 6-over spell (36 balls) according to ball speed and accuracy. A calibrated radar gun (Stalker ATS, Applied Concepts, Texas, USA) positioned approximately 5 m behind the bowlers arm was used to assess ball speed at the point of release. Bowling accuracy was assessed according to the Cricket Australia-Australian Institute of Sport grid-based accuracy system whereby each ball was numerically rewarded for its proximity to a pre-designated target (Portus et al., 2010). An infra-red timing system (Speed-light, Swift, Wacol, Australia) determined overall and final 5-m run-up speeds.

Before and after exercise, counter-movement jump height were assessed using a linear position transducer (G1706374B; Fitness Technology, Adelaide, Australia) interfaced with Ballistic Measurement System software (Fitness Technology, Adelaide, Australia). Participants completed a maximal, 10-repetition counter-movement jump protocol with the position transducer attached to a dowel rod across the shoulders to minimise arm swing and standardise jump technique. Linear position transducers are reported as a reliable (Intra-class correlation coefficient= 0.721 – 0.982; Co-efficient of variation= 2.1 – 11.7%) and valid (r= 0.861 – 0.959) measure of jump performance variables (Cronin, Hing & McNair, 2004).

For the duration of the bowling protocol, participants were fitted with an SPI Elite (GPSports, Canberra, Australia) global positioning system unit (1 Hz), harnessed between the scapulae at the base of the cervical spine. Data were downloaded (Team AMS, GPSports, Canberra, Australia) for analysis at the conclusion of each session and classified as either low-intensity activity (<7.0 $km \cdot h^{-1}$), moderate-intensity activity (7.0 – 14.4 $km \cdot h^{-1}$), high-intensity activity (>14.4 $km \cdot h^{-1}$) and very-high-intensity activity (>20 $km \cdot h^{-1}$) (Duffield, Coutts & Quinn, 2009b). Coutts and Duffield (2010) report the mean Co-efficient of variation of this model to be 0.5 – 3.2% for distances covered and 0.8 – 20% for pre-defined speed zones and peak speeds.

Physiological measures

A mid-stream urine sample was collected before each session for the assessment of urine specific gravity (Refractometer 503, Now. Nippon Optical, Works Co, Tokyo, Japan). Nude body mass was assessed before and after exercise with calibrated scales accurate to 0.05 kg (UC-321, A & D, Adelaide, Australia) to indicate non-urinal fluid loss. Participants wore a heart rate monitor throughout (FS1, Polar Electro Oy, Kempele, Finland) and ingested a telemetric core temperature capsule (VitalSense, Mini Mitter, Bend, USA) 5 h before each session to ensure passage into the gastro-intestinal tract. Heart rate and core temperature responses were recorded before the intervention, at 10 min increments during the intervention period, and before and after each over. Measures of skin temperature were recorded with an infra-red thermometer (ThermoScan 3000, Braun, Kronberg, Germany) (Burnham, McKinley & Vincent, 2006) at three sites (sternum, mid-forearm, and medial calf) and used to calculate mean-weighted skin temperature as per Burton (1934). Skin temperature was measured before the intervention, every 10 min during the intervention protocol, and before and after exercise.

Blood collection and biochemical analysis

Indirect measures of muscle damage, inflammation and stress responses to pre-cooling were assessed using venous blood samples drawn before and 30 min after exercise. Samples were collected using serum separator tubes (Monovette, Sarstedt, Numbrecht, Germany) and allowed to clot at room temperature before centrifugation (10 min at 4000 rpm). Serum was separated and stored at -20°C until analyses. Creatine kinase concentration was determined using an enzymatic method and bichromatic rate technique (Coefficient of variation= 3.0%), while C-reactive protein was assessed according to the particle-enhanced turbidimetric-immunoassay methods (Coefficient of variation= 3.8%; Dimension Xpand spectrophotometer, Dade Behring, Atlanta, USA). Insulin, testosterone and cortisol were measured using a solid-phase, competitive chemiluminescent enzyme immunoassay (Coefficient of variation= 2.8%, 4.3%, 2.1% respectively; Immulite 2000, Diagnostic Products Corp., Los Angeles, USA).

Perceptual measures

Rating of perceived exertion and thermal sensation were monitored as per the Borg CR-10 scale (0= nothing at all – 10= maximal) and an 8-point Likert scale (0= unbearably cold – 10= unbearably hot) respectively. Rating of perceived exertion and thermal sensation values were recorded at 10-min intervals during pre-cooling and after each over.

Statistical Analysis

Data are reported as mean ± standard deviation. A repeated-measures analysis of variance (ANOVA) compared treatments, with a Fisher's LSD applied for post hoc analysis. Significance was accepted as $P < 0.05$. Results were analysed with the Statistical Package for Social Sciences (SPSS v 17.0, Chicago, USA). Further, the magnitudes of change between conditions were calculated according to standardised mean differences (Cohen's d effect size), whereby an effect size of < 0.2 is classified as 'trivial', 0.2 – 0.4 as 'small', 0.5 – 0.7 as 'moderate' and > 0.8 as 'large' effects.

Results

Performance

Mean ± standard deviation ball speed and bowling accuracy are presented in Table 1. Overall total run-up and final 5-m run-up speeds are presented in Figure 1. There were no differences and only trivial-to-small effect sizes for mean ball speed (pre-cooling 114.5 ± 7.1 $km \cdot h^{-1}$ vs. control 114.1 ± 7.2 $km \cdot h^{-1}$; *P*= 0.63; d= 0.09) and bowling accuracy (pre-cooling 43.1 ± 10.6 AU vs. control 44.2 ± 12.5 AU; *P*= 0.76; d= 0.14). Mean and peak ball speeds for the respective 6 overs were not different between conditions (*P*= 0.12 – 1.00), with only trivial-to-small effect sizes demonstrated throughout (d= 0.05 – 0.31). There were no differences between conditions and small-to-moderate effect sizes for bowling accuracy scores attained during each over (*P*= 0.09 – 0.71; d= 0.32 – 0.78). Further, there were no differences and only trivial effect sizes apparent in overall total run-up speed (pre-cooling 19.08 ± 4.10 $km \cdot h^{-1}$ vs. control 19.25 ± 3.81 $km \cdot h^{-1}$; *P*= 0.66; d= 0.06) and final 5-m run-up speed (pre-cooling 21.70 ± 2.70 $km \cdot h^{-1}$ vs. control 21.56 ± 2.32 $km \cdot h^{-1}$; *P*= 0.31; d= 0.08). Similarly, run-up speeds did not differ at any stage of the bowling spell (*P*= 0.31 – 1.00; d= 0.001 – 0.19).

All time-motion measures were unchanged between conditions during the bowling spell (*P*= 0.31 – 1.00; d= 0.01 – 0.37; Table 2), though mean peak sprint speed was greater after Over 4 during pre-cooling trials (*P*= 0.03; d= 0.75; Table 2). There were no differences and only trivial-to-moderate effect sizes observed for all remaining between-over peak sprint-speed variables (*P*= 0.13 – 0.98; d= 0.02 – 0.63). Further, there were no differences (*P*= 0.22 – 0.50; d= 0.18 – 0.45) apparent for counter-movement jump height before (pre-cooling 39.6 ± 7.3 cm vs. control 40.6 ± 8.1 cm) or after the bowling spell (pre-cooling 41.8 ± 6.8 cm vs. control 39.3 ± 8.3 cm).

Physiological responses

While core temperature was not reduced during or immediately after the pre-cooling intervention (Figure 2A; *P*= 0.30 – 0.85; d= 0.17 – 0.45), large effect sizes indicate suppressed core temperature responses throughout the bowling spell (d= 0.91 – 3.44). These blunted responses were particularly evident before and after over 1 and after over 5 with core temperature reduced in pre-cooling trials (*P*= 0.01 – 0.04). Resting skin temperature was greater in the pre-cooling condition compared to control (Figure 2B; *P*= 0.03; d= 1.39). Nevertheless, skin temperature was lower with pre-cooling immediately after the intervention and before commencing the bowling spell (*P*= 0.003 – 0.01; d= 2.19 – 2.28). During the intervention, pre-cooling reduced heart rate at 10 min (Figure 2C; *P*= 0.08; d= 0.93) and 20 min (*P*= 0.01; d= 1.26); further, heart rate was reduced before each over for the duration of the bowling spell (*P*= 0.01 – 0.04; d= 0.96 – 1.74). Resting urine specific gravity did not differ between conditions (pre-cooling 1.016 ± 0.006 vs. control 1.016 ± 0.007; *P*= 0.81; d= 0.04), though sweat loss induced changes in body mass incurred during the bowling spell were reduced in pre-cooling trials (pre-cooling 1.46 ± 0.43 kg vs. control 1.86 ± 0.62; *P*= 0.01; d= 0.34). Finally, there were no differences and only trivial-to-moderate effect sizes detected for all venous blood measures of creatine kinase, C-reactive protein, insulin, testosterone and cortisol before or after the bowling spell (Table 3; *P*= 0.22 – 0.83; d= 0.05 – 0.72). However, creatine kinase response to the bowling spell was reduced in pre-cooling trials (*P*= 0.04; d= 1.10).

Perceptual responses

Results for rating of perceived exertion and thermal sensation are presented in Figure 3. Pre-cooling restrained rising rating of perceived exertion as the bowling spell continued, with reductions noted at over 5 (Figure 3A; $P = 0.004$; d= 0.93) and over 6 ($P = 0.001$; d= 1.81) respectively. Further, thermal sensation was lower throughout the intervention period and for the duration of the bowling spell in pre-cooling trials (Figure 3B; $P = 0.003 – 0.03$; d= 1.04 – 4.07).

Discussion

This study examined the effects of pre-cooling on bowling performance, physiological and perceptual responses during a 6-over spell of medium-fast bowling in the heat. Further, we evaluated the efficacy of a practical, mixed-method pre-cooling technique for cricket in a task-representative setting. While pre-cooling had no effect on skill-related bowling performance or run-up speed, an increase in between-over sprint speeds occurred after Over 4. Importantly, pre-cooling improved thermoregulatory control as physiological (heart rate, core temperature, skin temperature and sweat loss) and perceptual strain (rating of perceived exertion and thermal sensation) were reduced throughout the bowling spell. Accordingly, pre-cooling induced suppression of thermal demands provides medium-fast bowlers with small but still potentially worthwhile benefits indicated by a reduced physiological cost for a given bowling effort in hot conditions.

Although the benefits of pre-cooling for intermittent-sprint exercise in the heat have been reported (Duffield, 2008), ensuing effects on sport-specific skill performance are lacking (Hornery et al., 2007). The current data demonstrate trivial differences in bowling performance (ball speed and accuracy) between conditions and limited decline across the 6-over spell (Table 1). These findings are consistent with the minimal variation in ball speed or accuracy reported during 6 – 12-over spells in thermoneutral conditions (Burnett, Elliott & Marshall, 1995; Portus, Sinclair, Burke, Moore & Farhart, 2000; Duffield et al., 2009a). Accordingly, despite the exacerbated physiological demands of medium-fast bowling in the heat (Devlin et al., 2001), increased thermoregulatory control after pre-cooling demonstrates little influence over motor control and subsequent skill-based bowling performance. Climatic conditions aside, medium-fast bowlers appear capable of maintaining ball speed and accuracy for the duration of a 6-over spell (~45 min). However, given the reduced physiological demand to achieve a similar bowling performance, the influence of pre-cooling on bowling skills across longer or repeated spells is of future interest.

Combined with the transfer of momentum and the summation of segmental velocities during the bowling action, optimal speed of the run-up leading into the delivery stride is important to generate ball speed (Glazier, Paradisis & Cooper, 2000; Salter, Sinclair & Portus, 2007). Medium-fast bowlers must seek a balance between momentum and movement control at the point of ball release (Woolmer et al., 2008; Duffield et al., 2009a). Considering the paced and rhythmical nature of medium-fast bowling (Woolmer, et al., 2008), the lack of change in run-up speed with pre-cooling is not surprising (Figure 1). It is unlikely run-up speed would be increased by acute external interventions because of the risk of negative effects on technique and possible reductions in ball speed and accuracy. However, decreased muscle temperature arising from inappropriate cooling dosages or warm-up following cooling procedures could adversely affect voluntary force production and sprint performance (Skein et al., 2011), and so prevent optimal rhythm and momentum in the run-up. In context of the current data, a 10-min cricket specific warm-up after a 20-min pre-cooling strategy seems sufficient to avoid ergolytic effects on run-up characteristics, though practitioners are advised to trial such practices in training before implementing them in competition.

Unlike laboratory-based, self-paced intermittent-sprint protocols (Duffield & Marino, 2007; Minett et al., 2011), the largely standardised movement characteristics of the bowler's run-up and matched activity patterns between overs reported here resulted in no change in sub-maximal distances covered (Table 2). However, maintenance of higher 20-m peak sprint speed between overs occurred with pre-cooling as the spell progressed. Similarly, Castle et al. (2006) demonstrated that pre-cooling preserved peak power output during repeated-sprint cycling efforts. Accordingly, reduced thermal demands after pre-cooling might override reductions in muscle recruitment and voluntary force production otherwise observed in hot conditions (Kay et al., 2001), thus allowing the maintenance of optimal (higher) self-selected exercise intensities (Kay, Taafe & Marino, 1999; Duffield et al., 2010; Skein et al., 2011). Notably, while the bowling run-up involves a set distance at a consistent mean speed, the 20-m maximal sprint involved self-selected efforts that did not require sport-specific skill. Hence, the benefits of pre-cooling for medium-fast-bowling performance in the heat might not show in a single spell, though could maintain higher exercise intensity *'off the ball'* during fielding activity, particularly over prolonged durations.

Pre-cooling strategies enhance thermoregulatory control through an increased heat-storage reserve as physiological responses to raised environmental and metabolic heat production are reduced (Marino, 2002). The reduced thermal load before exercise (core temperature and skin temperature; Figure 2) and blunted core temperature response throughout the bowling spell could signify the combination of multiple cooling apparatus as an ecologically valid alternative to cold-water immersion for bowlers at risk of heat strain (Duffield et al., 2009c). Comparable transfer of physiological perturbations from laboratory-based interventions to the field (core temperature reduced ~0.2°C; Figure 2A) (Cotter, Sleivert, Roberts & Febbraio, 2001; Castle et al., 2006; Minett et al., 2011) using practical techniques could allow repeated cooling exposures and prolonged protection against excessively raised core temperature responses in hot conditions. As a result, this artificial preservation of thermoregulatory control could reduce sweat responses and evaporative heat loss mechanisms and so alleviate cardiovascular strain as a larger centralised blood volume is maintained (Wendt et al., 2007).

The consistent and repetitive physical demands of medium-fast bowling explain comparable heart rate responses between conditions after each over (Figure 2C). However, lower heart rate values before each over with pre-cooling could indicate reduced sweat loss alterations in blood volume that preserve cardiac output and ease cardiovascular strain (Marino, 2002). Despite the brevity of a 6-over bowling spell in the context of a cricket innings, 1.7 – 2.1% reductions in nude body mass occurred, with inter-trial sweat rate discrepancies of ~400 mL representing a preservation of hydration status with pre-cooling. Given the difficulties of access and consumption of adequate fluid replacement for cricketers during competition in hot conditions (Gore et al., 1993), greater heat removal might reduce sweat responses and so buffer excessive involuntary dehydration. Consequently, maintenance of hydration status with pre-cooling might lessen thermoregulatory and cardiovascular symptoms of heat strain in medium-fast bowlers, to the benefit of health (Driscoll et al., 2008; Finch & Boufous, 2008) and skill-related outcomes (Devlin et al., 2001).

Despite the reduction in thermal strain of medium-fast bowlers after pre-cooling, few differences occurred between conditions for indirect biochemical markers of muscle damage, inflammation or stress (Table 3). Nevertheless, changes in creatine kinase during the bowling spell were reduced in pre-cooling trials. Similar to others, these data indicate that increased thermoregulatory demands are associated with greater creatine kinase release from muscle fibres (Alzeer, el-Hazmi, Warsy, Ansari & Yrkendi, 1997) that is ameliorated with pre-cooling (Minett et al., 2011). However, given the sensitivity of cortisol to heat strain (Follenius, Brandenberger, Oyono & Candras, 1982) and the reduced thermal demands (physiological and perceptual) after pre-cooling, the lack of differences between conditions are unexpected, though not unknown (Hoffman et al., 1997). It is possible that a 6-over bowling spell is not long enough to evoke differences in biochemical stress responses between conditions and highlights a methodological limitation whereby peak concentrations are not be exhibited for several hours.

Finally, to complement a reduced physiological demand, perceptual strain (both rating of perceived exertion and thermal sensation) was largely suppressed throughout the bowling spell after pre-cooling (Figure 3). Lower subjective ratings of exertion and/or thermal sensation with pre-cooling are not novel, though often in free-paced activity these perceptual responses would be at least partially masked by higher intensities during intermittent-sprint exercise (Quod, Martin & Laursen, 2006; Skein et al., 2011). This finding probably reflects the unique physical requirements of cricket fast-bowling. It could also support integrative afferent and efferent feedback processes (lower physiological and perceptual demands) and explain higher 20-m sprint speeds as the bowling spell progressed (Tucker, 2009). Regardless, given the few differences in exercise performance and global positioning system unit data, pre-cooling in hot conditions eases subjective loads of the medium-fast bowler. Accordingly, while a 6-over spell represents only a portion of typical bowling demands, this apparent shielding of perceptual exertion after pre-cooling could provide ergogenic benefits as the duration of play is extended.

In conclusion, mixed-method whole-body pre-cooling had no effect on the skill-based performance of medium-fast bowlers in the heat. Although the brevity of a single 6-over spell might have contributed to the absence of conditional differences in skill performance, higher sprint speeds occurred during simulated fielding activity as the spell progressed. Further, the combination of multiple, practical cooling apparatus presents practitioners with an alternative to traditional immersion cooling techniques that improves physiological and perceptual states of medium-fast bowlers in hot conditions. Used strategically in the field, this mixed-method approach to pre-cooling could protect unacclimatised or at-risk players against environmental- and exercise-induced heat strain, blunting thermoregulatory demands and improve the quality of the session.

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Table captions

Table 1. Mean ± standard deviation ball speed, peak ball speed and bowling accuracy per over during a 6-over spell.

Table 2. Mean ± standard deviation time-motion analysis of selected movement patterns, distances covered and peak sprint speed achieved between overs during a 6-over bowling spell. [a] represents a difference between conditions ($P < 0.05$).

Table 3. Mean ± standard deviation biochemical comparison between conditions. [a] represents a difference between conditions ($P < 0.05$). [1] represents a large ES between conditions ($d > 0.80$).

Figure captions

Figure 1. Overall total run-up and final 5-m run-up speed for each ball of a 6-over spell.

Figure 2. (A) Mean ± standard deviation core temperature, (B) mean ± standard deviation skin temperature and (C) mean ± standard deviation heart rate between conditions. * represents a difference between conditions ($P < 0.05$). # represents a large ES between conditions ($d > 0.80$).

Figure 3. (A) Mean ± standard deviation rating of perceived exertion and (B) mean ± standard deviation thermal sensation scale between conditions. * represents a difference between conditions ($P < 0.05$). # represents a large ES between conditions ($d > 0.80$).

Table 1

Variable		Over 1	2	3	4	5	6
Bowling Performance							
Mean speed ($km \cdot h^{-1}$)	CONT	114.8±6.8	114.5±6.1	114.8±5.6	114.1±5.8	113.5±5.9	113.6±6.7
	COOL	114.4±6.3	115.8±6.8	115.6±6.6	114.3±6.6	113.9±6.5	114.1±7.4
Peak speed ($km \cdot h^{-1}$)	CONT	116.4±6.2	117.1±5.9	116.9±5.8	116.0±6.2	115.8±6.6	116.0±6.3
	COOL	117.3±6.3	118.3±6.7	118.3±7.0	117.2±7.1	116.7±7.2	116.8±7.2
Mean accuracy (AU)	CONT	46.8±17.3	48.9±21.4	39.4±16.2	43.1±16.0	45.1±23.2	44.4±20.0
	COOL	39.9±15.0	44.1±20.0	48.2±15.7	39.2±18.7	37.8±19.0	54.8±18.4

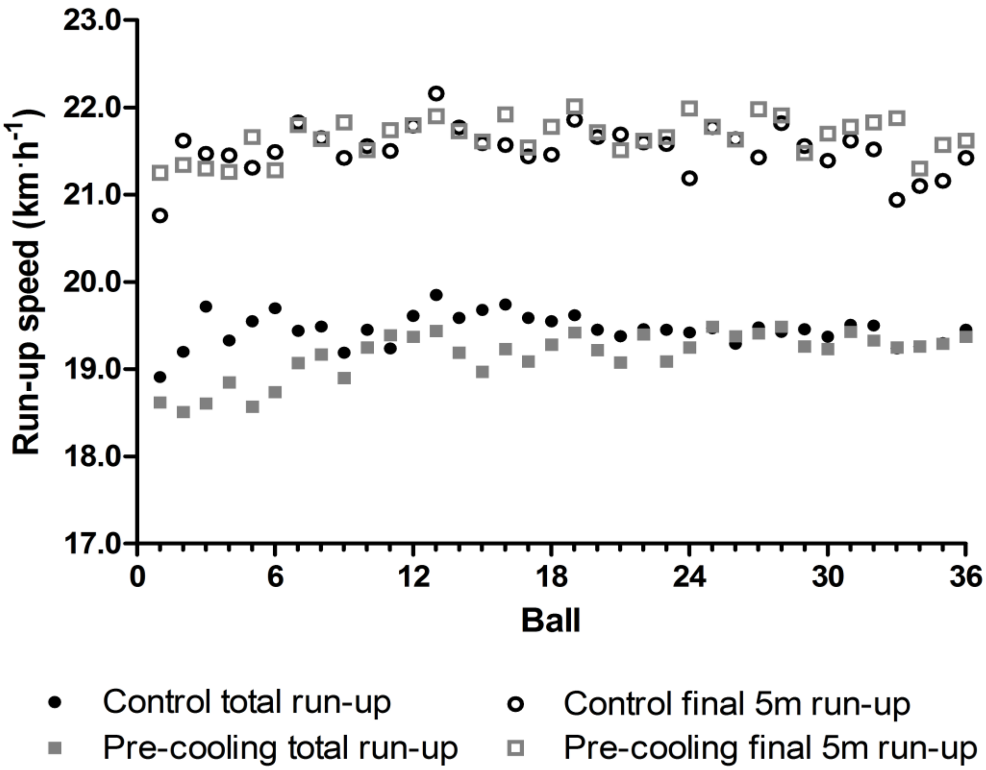
Table 2

	Control	**Pre-cooling**
Distance (m)		
Total	4328 ± 707	4336 ± 666
Very-high-intensity activity	442 ± 287	425 ± 299
High-intensity activity	888 ± 230	866 ± 223
Moderate-intensity activity	461 ± 75	476 ± 114
Low-intensity activity	2537 ± 411	2568 ± 316
Speed ($m \cdot s^{-1}$)		
Very-high-intensity activity	5.8 ± 0.5	5.6 ± 0.8
High-intensity activity	5.2 ± 0.6	5.2 ± 0.5
Moderate-intensity activity	3.1 ± 0.1	3.01 ± 0.9
Low-intensity activity	1.0 ± 0.1	1.1 ± 0.1
Peak sprint speed ($km \cdot h^{-1}$)		
Over 1	21.7 ± 3.1	22.7 ± 2.1
Over 2	22.1 ± 2.5	21.9 ± 2.3
Over 3	21.0 ± 2.5	22.1 ± 2.3
Over 4	20.9 ± 2.2	22.1 ± 2.2[a]
Over 5	21.3 ± 2.2	21.3 ± 2.7

Table 3

	Control			Pre-cooling		
	Before	After	Δ	Before	After	Δ
Creatine Kinase ($U \cdot L^{-1}$)	229 ± 85	389 ± 114	161 ± 132	272 ± 85	355 ± 120	82 ± 54[a1]
C-reactive protein ($U \cdot L^{-1}$)	3.0 ± 3.5	3.5 ± 3.6	0.4 ± 0.9	2.3 ± 1.0	2.7 ± 1.4	0.4 ± 0.8
Insulin ($\mu L \cdot mL^{-1}$)	6.9 ± 4.7	6.1 ± 3.2	-0.8 ± 5.9	6.4 ± 2.5	6.5± 3.0	0.1 ± 2.0
Testosterone ($ng \cdot dL^{-1}$)	431 ± 49	449 ± 86	18 ± 81	409 ± 50	445 ± 95	37 ± 65
Cortisol ($nmol \cdot L^{-1}$)	216 ± 95	408 ± 160	192 ± 121	223 ± 53	441 ± 171	219 ± 175

Figure 1



Run-up speed (km·h-1)
23.0
22.0
21.0
20.0
19.0
18.0
17.0
0
6
12
18
24
30
36
Ball
Control total run-up
Control final 5m run-up
Pre-cooling total run-up
Pre-cooling final 5m run-up

Figure 2

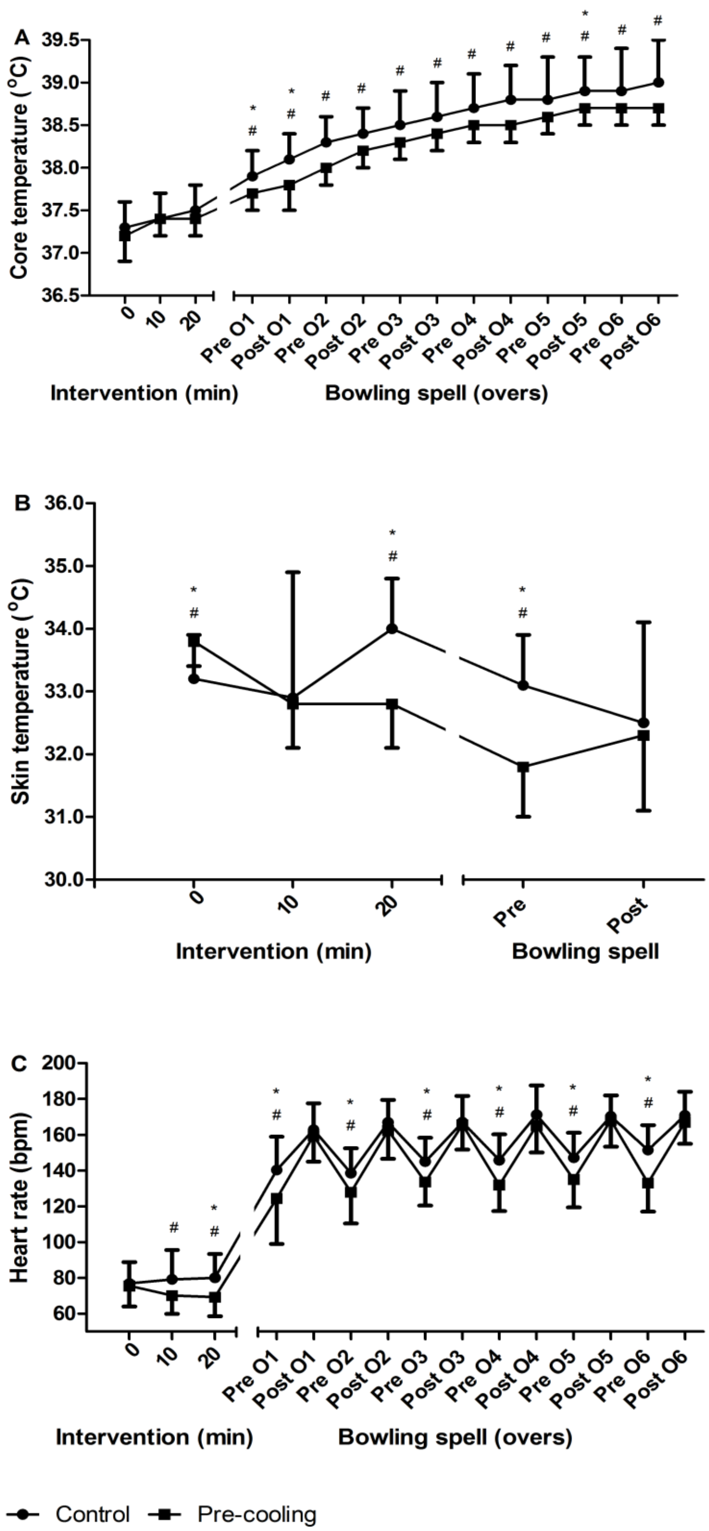
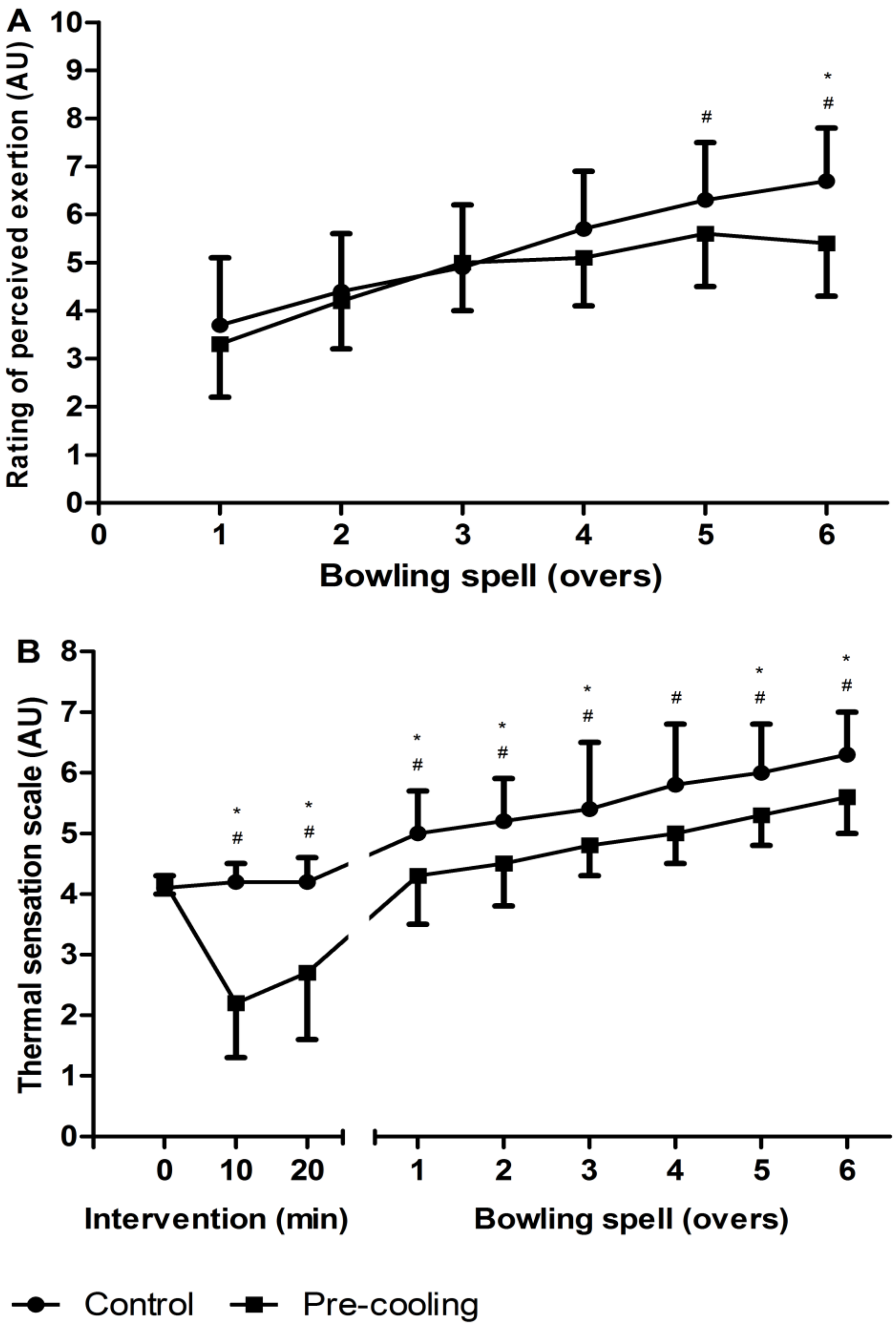

A
Core temperature (°C)
Intervention (min)
Bowling spell (overs)
B
Skin temperature (°C)
Intervention (min)
Bowling spell
C
Heart rate (bpm)
Intervention (min)
Bowling spell (overs)
Control
Pre-cooling

Figure 3


A
Rating of perceived exertion (AU)
Bowling spell (overs)
B
Thermal sensation scale (AU)
Intervention (min)
Bowling spell (overs)
Control
Pre-cooling